

Deep Space Network to Viking Orbiter Telecommunication Link Effects During 1976 Superior Conjunction

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Viking superior conjunction occurred November 25, 1976 with an angular separation between the sun and Mars of one-quarter degree. For three years prior to this date, the Viking Project and the Deep Space Network had planned the spacecraft and ground station activities and configuration during the three-month superior conjunction period. This article describes, in a narrative and qualitative manner, the planning for and the observations made during Viking superior conjunction. These results are built upon observations made during previous Mariner missions and will, in turn, be useful for the next Viking conjunction and for future Mariner-class superior conjunction planning.

I. Background

The end of the Viking primary mission was determined in part by the onset of the superior conjunction. Superior conjunction is the period of time when the spacecraft is nearly behind the sun as seen from the deep space tracking stations on the earth. Previous tracking experience, on Mariner Mars 1969, Mariner Mars 1971, Mariner Venus-Mercury 1973, had demonstrated that significant communication link degradation can occur whenever the angular separation of the spacecraft and the sun, as seen from the tracking station, is small.

The minimum angular separation of the spacecraft and the sun occurred on November 25, 1976 when the Viking spacecraft, in orbit around Mars for the Orbiters and on the surface of Mars for the Landers, were 0.25 deg from the center of the sun. For several hours, the spacecraft actually were occulted behind the edge of the solar disc, and no uplink or downlink

communications were possible. For about one month on either side of November 25, the angular separation (called sun-earth-probe angle) was less than 10 deg and significant perturbations occurred in the downlink telemetry.

This article discusses primarily four link quantities: uplink carrier signal strength; downlink carrier signal strength; signal-to-noise ratio for the Orbiter low-rate engineering telemetry channel; and signal-to-noise ratio (SNR) for the high-rate science data channel. In addition, some mention is made of the low bit error rate and the high bit error rate, on the basis of counted bit errors in known frame synchronization words.

II. Viking Superior Conjunction Predictions

The Project required link predictions for planning the mission activities. It was critically important to know the latest

time it was prudent to command the Orbiter prior to minimum sun-earth-probe angle. It was important to know the dates when the high-rate channel should be switched to lower data rates so as to maximize the total amount of scientific data returned without undue risk of losing the data entirely because of the degraded link conditions.

The successive Mariner Projects and Viking each generated superior conjunction link predictions on the observed experience of the previous projects. The original Viking predictions were made on the basis of observed degradation which occurred during Mariner Mars 1969 and Mariner Mars 1971 superior conjunctions. As these Projects had available during their superior conjunctions only low-gain antennas, the only data quantities for which degradation could be determined at the receiving stations were S-band downlink carrier strength and single-subcarrier 8-1/3-bit/second (bps) telemetry data signal-to-noise ratio.

The amount of degradation is known to be a function of (a) the activity of the sun and (b) the angle between the ground receiving antenna boresight and the sun. The Viking superior conjunction would occur during the minimum level of the 11-year solar activity cycle. However, observations during previous conjunctions made it clear that day-to-day solar variations also had significant effects on the S-band communications links.

The major degradation factors are defined as (a) the noise temperature increase occurring at the Deep Space Station and (b) spectral spreading or "scintillation." The noise temperature increase is caused by the ground antenna sidelobes or main beam pointing toward the solar disc. The S-band receiving system noise temperature was predicted to increase from a normal of 20 to 25 kelvins at a 64-meter station to several thousand kelvins. In addition, for sun-earth-probe angles of less than about 2 degrees, large variations during the period of a single station pass were predicted. These variations were due to the "quadripod effect," named for the four-legged support structure holding the antenna subreflector. This structure creates asymmetries in the antenna pattern, primarily sidelobes which cross the solar disc.

For most closed-loop operations, the dominating degradation factor is the spreading of the uplink and downlink signal spectra from a line to several tens of hertz for small sun-earth-probe angles. The Viking observations did not separate these two causes.

The Viking predictions appear in Figs. 1 and 2. Figure 1 shows the predicted sun-earth-probe angle as a function of calendar date late in 1976. The minimum angle was predicted to be approximately one-quarter of a degree, with Mars

actually being obscured from earth by the solar disc for about half a day. Figure 2 shows the predicted degradation for the S-band downlink carrier strength and for the 8-1/3-bps single-subcarrier telemetry uncoded signal-to-noise ratio, each prediction a function of calendar date. The predictions are given in three curves. Curve A defines the predicted "peak-to-peak" variation expected on either the downlink carrier level or the signal-to-noise ratio during a given day's pass. Curve B defines the average degradation in the S-band downlink carrier level (but excluding the peak-to-peak variation just mentioned). Curve C similarly defines the average degradation of the low-rate telemetry signal-to-noise ratio. The degradation curves are based on Mariner Mars 1971 observed degradations as a function of the sun-earth-probe angle, with these angles translated to Viking calendar dates by means of Fig. 1.

III. Mariner Venus-Mercury 1973 Experience

The Mariner Venus-Mercury 1973 superior conjunction occurred at a time intermediary between the generation of the Viking predictions and the flight mission itself. This spacecraft included several new features of interest to Viking. It had an articulated high-gain antenna for the downlink, although the uplink was received via a low-gain antenna. It also had an experimental X-band transmitter, of the same type as would be used on Viking. And it also had dual-subcarrier downlink telemetry mode, with the high-rate channel coded, just as Viking although with different bit rates. The minimum sun-earth-probe angle of 1.66 deg occurred on June 5, 1974.

Figure 3 compares the previous superior conjunctions with that predicted for Viking, as the information was available in the autumn of 1974. Solar activity is defined, in this figure, in terms of two quantities: sunspot number and "Ottawa flux." These quantities are predicted, observed, and published. The "Ottawa flux" is measured at 2800 MHz at the Ottawa (Canada) solar observatory. The units are watts per square meter per hertz $\times 10^{-22}$. To indicate the variability of sunspot number and Ottawa flux, the mean and standard deviations for the day of minimum sun-earth-probe angle are given.

On the earlier Mariner Mars 1971 mission, downlink telemetry had been blacked out for 20 days. In contrast, on Mariner Venus-Mercury 1973, S-band single-subcarrier telemetry was received throughout the conjunction period, although the bit error rate increased as the sun-earth-probe angle decreased. The difference between these two missions is attributed to two factors: the larger minimum sun-earth-probe angle; and the use of the high-gain antenna for the Mariner Venus-Mercury 1973.

Mariner Venus-Mercury observation data appear in Fig. 4. On this mission the superior conjunction caused a relatively slight degradation in the observed S-band downlink signal level and a somewhat greater degradation in the 33-1/3-bps signal-to-noise ratio. Comparing these degradations with those predicted for Viking showed (a) considerably smaller S-band carrier degradation than predicted for Viking, and (b) very nearly the same low-rate signal-to-noise degradation as predicted for Viking.

The Viking Project had great interest in being able to predict the degradation of block-coded high-rate data because the Orbiters would be accumulating scientific data right up to the end of the primary mission, limited only by the predicted solar effects of superior conjunction. There was no good theoretical basis for rationalizing whether high-rate coded data should be degraded more or less compared with low-rate uncoded data. A limited amount of Mariner Venus-Mercury dual-subcarrier operation occurred, down to a sun-earth-probe angle of 3.2 deg. This, by coincidence, corresponded to a time in the Viking mission 10 days before minimum sun-earth-probe angle and equal to the defined end of the Viking primary mission, which was November 15, 1976. Analysis of the Mariner Venus-Mercury 7350-bps block-coded data showed a mean degradation of 1.7 dB from the predicted signal-to-noise ratio of 5.3 dB. The standard deviation, indicating the amount of scatter on the data, was 1.1 dB. User comments on data quality were that the quality was poor and very noisy, even though the observed signal-to-noise ratio of 3.6 dB compares favorably with the "threshold" value of 3.0 dB assumed for Viking planning.

Noting briefly the radiometric data, the S-band doppler was too noisy to be usable for orbit determination on Mariner Mars 1969 and Mariner Mars 1971. The Mariner Venus-Mercury 1973 two-way S-band doppler and S-band ranging was usable through conjunction, although the noise level did increase. As for the X-band downlink, which provided a radio-frequency carrier for doppler tracking and ranging modulation modulated on the carrier, these radiometric quantities were too noisy to be of use on Mariner Venus-Mercury 1973.

The Mariner Venus-Mercury observations and their implications to Viking were presented at a meeting of the Viking Telecommunications Working Group on September 24, 1974. These observations proved (for the first time) that downlink telemetry data can be maintained to a sun-earth-probe angle of 1.6 deg and that high-rate coded data can be maintained to a sun-earth-probe angle of 3.2 deg. The predicted outlook for the Viking primary mission was good.

IV. Viking Orbiter Telecommunications Observations During Superior Conjunction

For the Viking superior conjunction, the spacecraft and network were configured as follows:

- (1) Orbiter ranging channel "ON."
- (2) Orbiter X-band transmitter "ON."
- (3) Downlink in "cruise" mode (single-subcarrier) at 8-1/3-bps.
- (4) High-gain antenna pointing updated frequently enough to limit pointing error to less than 0.5 deg.
- (5) Ground transmitter power level 50 kW for overseas stations and 100 kW for DSS 14 for the 64-m stations.
- (6) Deep Space Station personnel to include in the post-track teletype report hourly readings of S-band and X-band system noise temperature.

Within one month of November 25, 1976, a set of "standard" predictions were used by the Telecommunications Unit to assess link degradation. These neglected the slightly changing earth-to-Mars distance and the effects of station elevation angle on system noise performance. The predictions included:

Uplink carrier level (command and ranging modulation (ON))	-130 dBm (26-m station, 20 kW)
	-117 dBm (64-m station, 50 kW)
S-band downlink carrier level (single subcarrier, ranging ON)	-151.5 dBm (26-m stations)
	-143.0 dBm (64-m stations)
X-band downlink carrier level	-153.0 dBm (64-m stations only)
Signal-to-noise ratio	+20 dB (26-m stations, 8-1/3 bps)
	+30 dB (64-m stations, 8-1/3 bps)

Following is a qualitative "snapshot" of link conditions existing just before the total loss of downlink data. Included are some typical digital television displays of the link quantities, generated in plot format by the Viking mission and test computer. This "snapshot" is for November 23, 1976, at the start of the DSS 14 pass, when the sun-earth-probe angle was about 0.7 deg.

- (1) *Downlink S-band signal level.* The two-way S-band downlink was degraded as much as 5 to 10 dB during

some station passes. The one-way downlink was not degraded more than 5 dB.

- (2) *Downlink X-band signal level.* Degradation exceeded 20 dB in the two-way mode, with values of -170 to -175 dB below 1 mW. The degradation was only about 2 dB in the one-way mode and fairly stable.
- (3) *Low-rate signal-to-noise ratio.* This parameter was also affected by the two-way or one-way operation, when the sun-earth-probe angle was smaller than 2 deg. It also varied considerably over long periods during a single station pass, possibly due to the quadripod effect, causing an increase in system noise temperature. The indicated signal-to-noise ratio, in the station telemetry and command processor computer, was as low as 2 to 3 dB at 64-m stations, sometimes, and as high as 7 or 8 dB.
- (4) *Bit error rate for the low-rate data.* Bit error rate was quite variable, going from a low of 6×10^{-3} to as high as 4×10^{-2} . This variability is consistent with the variability noted in the signal-to-noise ratio. The bit error rate was significantly higher at 1-deg sun-earth-probe angle than it had been at 2 deg.
- (5) *Uplink carrier signal level.* The average uplink carrier level was degraded by 1 dB at the most. The scatter was 5 dB peak-to-peak at this time, although scatter of as much as 8 dB peak-to-peak had been noted at 2 deg sun-earth-probe angle. These values are for 64-m stations, at 50 or 100 kW.

Computer-generated plots of these data are shown in Fig. 5, where the link is not disturbed greatly by the sun. Figures 6 through 10 then can be compared with Fig. 5 to show the increasing effects of superior conjunction on uplink and downlink quantities.

Figure 6 begins to show the solar effects. This is a composite of several digital television plots which have been combined to show the simultaneous effects on (a) two downlink receivers at DSS 14, (b) the low-rate signal-to-noise ratio, (c) the high-rate signal-to-noise ratio, and (d) the uplink carrier strength, as telemetered via the low-rate channel. This figure also shows Viking Orbiter 1 data, as did Fig. 5, but on November 10, 1976 when the sun-earth-probe angle was slightly larger than 4 deg. The top two plots in Fig. 6 show the downlink carrier as received by the two Block IV receivers at DSS 14 (Receivers 3 and 4). On this pass, Receiver 4 had reasonably steady performance, although the scatter is larger than the downlink carrier shown in Fig. 5, almost two months

earlier. The "glitching" (upward vertical lines from the average level) on Receiver 3 was *not* caused by solar effects, since the same S-band downlink is not disturbed on Receiver 4. It was necessary to use cross-checks of this type, when possible, to eliminate "artifacts" caused by factors other than the sun.

The third plot on Fig. 6 shows the low-rate 8-1/3-bps signal-to-noise ratio. At approximately 1 hour and 20 minutes after the start of this plot, the Orbiter switched from the single-subcarrier to the dual-subcarrier mode. Under normal conditions, the low-rate telemetry decreases from a "saturated" value of about 23 dB in the single-subcarrier mode down to about 12 dB in the dual-subcarrier mode. Strikingly, on this figure, there is virtually no difference in the estimated signal-to-noise ratio in the two different modes.

One of the significant observations during Viking superior conjunction was that the estimated low-rate signal-to-noise ratio began to degrade more than one month prior to the time of minimum sun-earth-probe angle, much more so than would be expected from the counted bit error rate. On the other hand, the estimated high-rate (block-coded) signal-to-noise ratio did not degrade significantly until quite small sun-earth-probe angles. At the same time, the counted bit error rate for the high-rate block-coded data was much worse than would be expected from the signal-to-noise ratio. This effect is displayed by comparing the bottom three plots of Fig. 6. The fourth-from-top plot shows the estimated high-rate signal-to-noise ratio. It averages 7 or 8 dB. Were this correct, the bit error rate would be almost zero. The bottom plot shows the telemetered uplink carrier level. The large number of vertical bars during the period of high-rate mode operation indicates that the bit error rate was very high. (Each vertical spike indicates a bit error in a significant bit of the telemetered data.) Upon switch to the single-subcarrier mode, the amount of spiking decreases to zero. Another interesting effect on the links can be observed by comparing the bottom plot of Fig. 6 with the top plot of Fig. 5. Both are uplink carrier levels. In Fig. 5, well before superior conjunction, the scatter is at most 3 dB peak-to-peak, whereas in Fig. 6, only 15 days before minimum sun-earth-probe angle, the scatter has increased to about 6 dB peak-to-peak, and there are longer-term variations evident also. During the high-rate mode operation, the counted bit error rate was about 1 in 100. The "predicted" bit error, neglecting solar effects is about 1 in 10,000. Thus, the actual bit error rate was more than two orders of magnitude higher than would be indicated by a Gaussian noise distribution.

Additional insight into the solar effects on telemetered Orbiter data during this same station pass can be gained through examination of Fig. 7. The telemetry channels shown are (a) the pitch cruise sunsensor position and (b) the yaw

cruise sunsensor position, in the Orbiter attitude control subsystem. The vertical axes are data numbers, and the curves indicate the "limit cycles" of these sensors. Approximately the first one hour of the plots occurred while the Orbiter was in the single-subcarrier telemetry mode. This mode results in more of the Orbiter's downlink power being concentrated in the telemetry subcarrier than occurs in the dual-subcarrier mode. The bit rate of the low-rate subcarrier is 8-1/3-bps. When the downlink changed from the single-subcarrier to the dual-subcarrier mode, the bit error rate went from approximately 1 in 1000 to 1 in 100. In addition, on the plot, when the dual-subcarrier mode existed, the computer processed the high-rate data, which is at a bit rate of 1 kbps. Thus, in the high-rate mode, there are many more data points displayed per unit time. The result is that the bit errors predominate in the displayed data. As had been observed on previous Mariner projects, "structured" telemetry data, such as these attitude control limit cycles, are relatively immune to even a high bit error rate. With some imagination, one can discern the continuing trends in the limit cycles even through the very high bit error rate.

November 10, 1976 was the last date in which the dual-subcarrier data mode was used. Link conditions continued to degrade even after the single-subcarrier mode, with data set to the lowest possible bit rate, 8-1/3-bps. Figure 8 shows the link data on November 15, 10 days prior to the time for the minimum sun-earth-probe angle. The sun-earth-probe angle was 3 deg. The telemetered uplink signal strength shows a scatter of 10 dB peak-to-peak, the maximum amount observed during the Viking superior conjunction. The scatter seemed to decrease somewhat, to about 7 dB peak-to-peak, just prior to the total loss of downlink data. The cause for this is not known; possibly solar activity was slightly greater at the earlier date. Comparing the middle and bottom plots of Fig. 8 with the comparable data in Fig. 5, the downlink S-band signal level and the low-rate channel signal-to-noise ratio do not show much more scatter than is normal well away from superior conjunction. This is thought to be due to the heavy "weighting" which exists in the Deep Space Network software which displays the signal level and the signal-to-noise ratio. In terms of the predicted signal levels without solar effects:

- (1) The uplink signal *mean* residual is not more than 1 dB, but there is a large amount of scatter about this mean value.
- (2) The S-band downlink carrier level also shows little average degradation, not more than 1 dB.
- (3) The 8-1/3-bps signal-to-noise residual shows a very large degradation, with an observed value averaging 2 dB against a predicted value of 20 dB for the 26-m DSS 61 performance.

- (4) The bit error rate was not counted; however, the top plot shows that there are few high-order bit errors (four vertical spikes only) during 4 hours of tracking, compared with a bit error rate of 1 in 25 expected for 2-dB signal-to-noise ratio.

The final plots shown were taken on November 22, 1976, 3 days before the minimum sun-earth-probe angle, when this angle was under 1 deg. Figure 9 displays the link information for VO-1 which was one-way with DSS 14 and DSS 43 during this time. The stations' Receivers 1 and 2 were locked to VO-1 S-band downlink. At the same time, Fig. 10 displays the VO-2 link data. VO-2 was two-way with DSS 14 during a portion of its pass, and later was two-way with DSS 43 during a portion of that pass. In each station, Receiver 3 was locked to the VO-2 S-band downlink, and Receiver 4 was locked to the VO-2 X-band downlink. The bottom plot in each portion of the figure is the 8-1/3-bps signal-to-noise ratio.

The difference between one-way and two-way operation is apparent in Fig. 10. DSS 14 X-band receiver was unable to lock to the X-band downlink at all during two-way operation, whereas it received X-band with not more than 2 dB of signal level degradation during one-way. DSS 43 was able to lock to X-band downlink in two-way, but the indicated signal level was degraded between 10 and 15 dB compared with one-way operation. As for the low-rate signal-to-noise ratio, it was quite variable during the DSS 14 pass and less variable during the DSS 43 pass. There are other variations in S-band and X-band downlink carrier level (particularly near 6 hours on the plot) that do not have a known cause, unless it be receiver bandwidth setting or other configuration effect. The indicated signal-to-noise ratio did not seem to be affected at that time. Conversely, at about 9 hours on the plot, the signal-to-noise decreased to near zero, but the S-band downlink carrier level did not change significantly. Again, a configuration effect is suspected, or possibly severe noise temperature increases, "quadripod effect."

The VO-1 quantities in Fig. 9 show less overall variation than the VO-2 quantities in Fig. 10. The latter have been discussed. For VO-1, the top plot shows that significantly more bit errors occurred (vertical lines) near 4 hours and near 9 hours on the plot. The cause of these is not known, nor that of the changes in signal-to-noise ratio (bottom plot) just before 5 hours and after 8 hours. Again, configuration changes to optimize radioscience data may be the cause, as the superior conjunction period of the Viking mission emphasized radioscience experiments.

Qualitatively, the links recovered in the reverse order and at about the same rate, as a function of sun-earth-probe angle, as they degraded going into superior conjunction. To first order,

the performance a given number of days later than November 25, 1976 was the same as that number of days before November 25.

By January 1, 1977, the only residual effects seen in the links were:

- (1) The uplink carrier level still showed more scatter about its average value than is typical well away from the sun.
- (2) The low-rate signal-to-noise ratio, particularly at 8-1/3 bps, still showed 1- to 2-dB degradation. This was of no operational concern, since the channel had more than adequate margin.

V. Assessment of Superior Conjunction Prediction Capability

The residuals for the S-band downlink signal level and the single-subcarrier, low-rate uncoded, signal-to-noise ratio are shown in Figs. 11 and 12. A "residual" is the algebraic difference between the link quantity predicted and the quantity observed during the tracking pass. All basic Viking Orbiter link predictions were made on the basis of no solar degradation. Thus, the observed degradation would show up directly as an increasingly negative residual.

The data in Figs. 11 and 12 are for Viking Orbiter 2; that for Viking Orbiter 1 is similar. The "nominal" and the "worst case" degradation values from Fig. 2 are indicated. As can be seen in Fig. 11, the actually observed S-band downlink signal level residuals were usually equal to or smaller than the nominal degradation predictions. The actually observed degradation of the low-rate signal-to-noise ratio (Fig. 12) is somewhat greater than the "nominal," but somewhat less than the "worst case."

VI. Summary and Conclusions

The minimum sun-earth-probe angle on the Viking mission occurred on November 25, 1976.

The first evidence of solar effects was that the single-subcarrier signal-to-noise ratio gradually came out of "saturation" at the 64-m stations. The next sign was an increase in the scatter observed on the uplink signal level, then on the downlink S-band signal level. Deep into conjunction, the bit error rate on the coded high-rate data in the dual-subcarrier mode increased greatly, compared to the indicated signal-to-noise ratio. Finally, the X-band carrier level showed great variations between times when there was an uplink to the Orbiter ("two-way") and the times when the Orbiter had no uplink ("one-way"). This effect had also been noted on the Mariner Venus-Mercury spacecraft during its superior conjunction, and was caused by uplink carrier degradation being multiplied by the ratio of the X-band and the S-band frequencies during two-way operation.

For two successive days nearest the minimum sun-earth-probe angle of 0.25 deg, no closed-loop receiver lock could be maintained even at 64-m tracking stations. This is not unexpected, considering that for several hours on November 25, the geometric raypath from Mars to earth passed through the "edge" of the solar disc. The radio science experimenters obtained "some" open-loop receiver data during the time that closed-loop receiver lock was lost. Following this time, as the sun-earth-probe angle increased, the link degradations gradually decreased. Performance was symmetrical going in and coming out, and generally followed the predicted degradations stated three years before the fact.

As during previous superior conjunctions, there was close cooperation between the Deep Space Network operations personnel, the Project telecommunications analysts, and the radio science investigators.

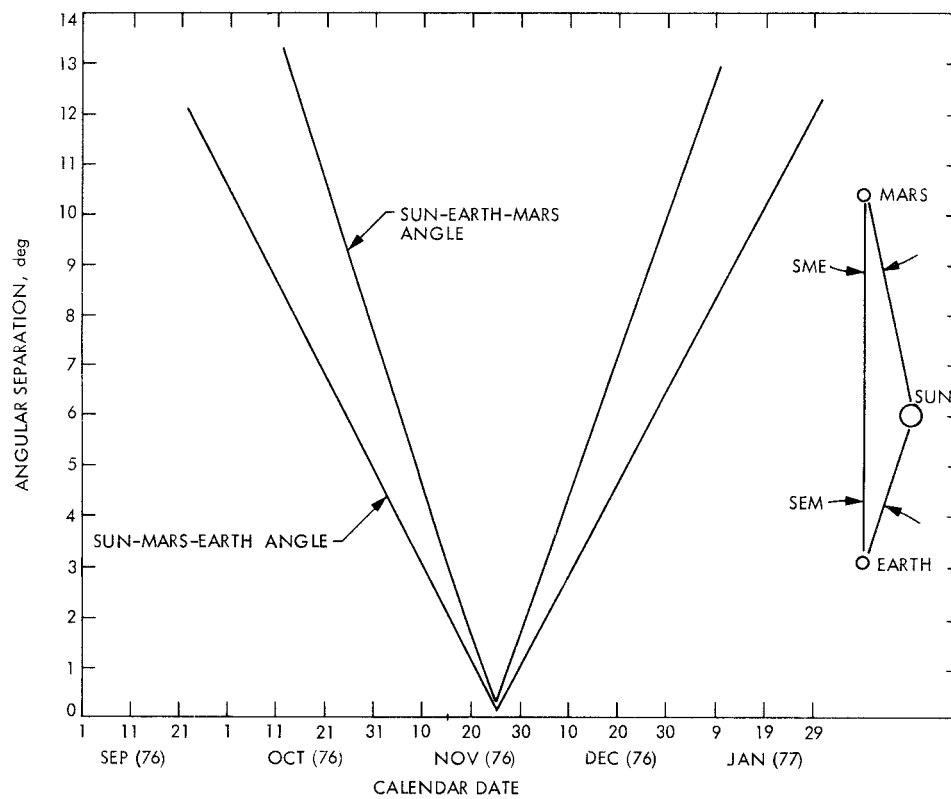


Fig. 1. Angular separation as a function of calendar date

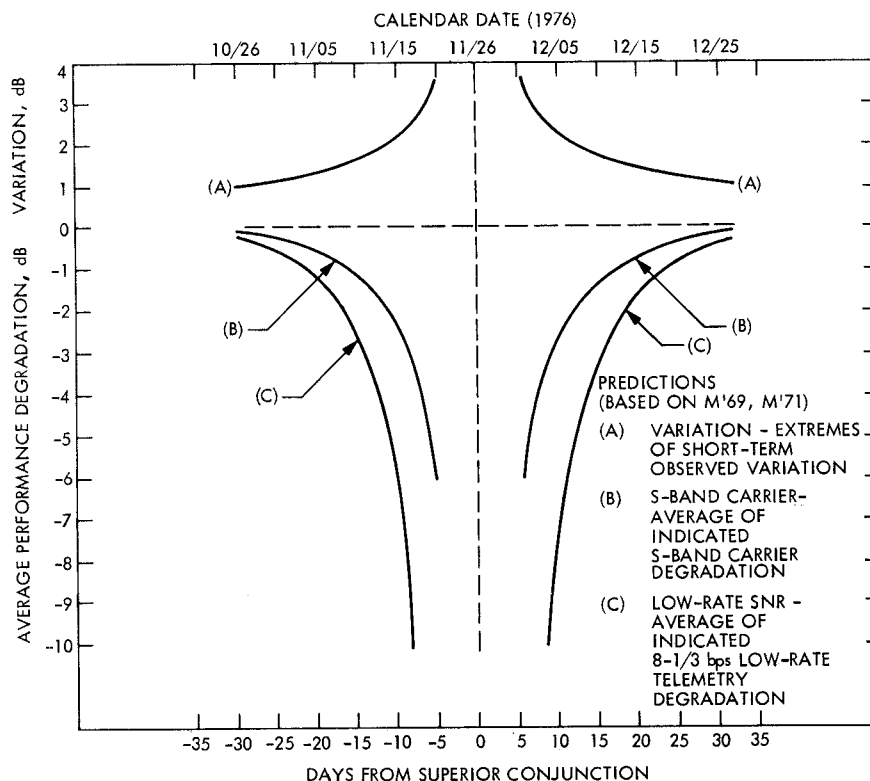


Fig. 2. Predicted degradation of Viking Orbiter links

	MARINER MARS 1969	MARINER MARS 1971	MARINER VENUS-MERCURY 1973	VIKING MARS 1975
DATE OF MINIMUM SEPARATION	4/30/70	9/7/72	6/5/74	11/25/76
MINIMUM SUN-EARTH-PROBE ANGLE	0.95°	1.05°	1.66°	0.23°
PREDICTED SOLAR ACTIVITY	MED-HIGH	MED	LOW	LOW
ACTUAL SOLAR ACTIVITY	MED-HIGH	MED-HIGH WITH FLARES	LOW-MED WITH FLARES	TBD*
AVERAGE SUNSPOT NUMBER				
MEAN	120.1	66.5	40.4	APPROX 40
STANDARD DEVIATION	30.1	24.3	31.9	
AVERAGE 2800-MHz SOLAR FLUX				
MEAN	167.8	121.6	90.7	APPROX 80
STANDARD DEVIATION	22.7	15.9	12.4	
COMMUNICATIONS CONFIGURATION AND MODE	LGA, 64-m S-BAND 8-1/3 bps	LGA, 64-m, S-BAND 8-1/3 bps	HGA, 64-m, S/X-BAND 33-1/3 bps RECEIVE LGA, S-BAND	HGA, 64-m, S/X-BAND 33-1/3 bps RECEIVE HGA, S-BAND
DOWNLINK BLACKOUT FOR TELEMETRY	?	20 days	NONE, BUT INCREASED BIT ERROR RATE	NONE EXPECTED IF CRUISE MODE
RADIO METRIC DATA	S-BAND RANGING	S-BAND RANGING	S-BAND RANGING NOISY S-BAND DOPPLER 1-WAY X-BAND DOPPLER	S/X-BAND RANGING S/X-BAND DOPPLER
COMMAND BLACKOUT PLANNED	?	20 days	20 days	TBD

*TBD = TO BE DETERMINED

Fig. 3. Comparison of superior conjunction characteristics

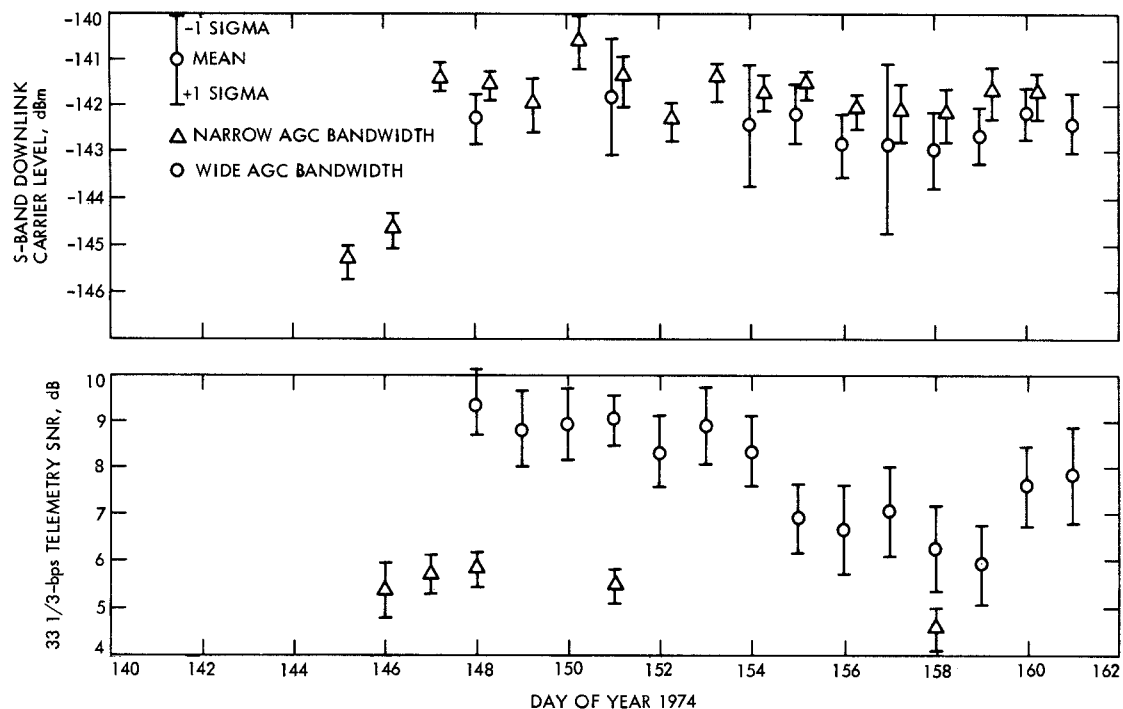


Fig. 4. Mean and standard deviation of Mariner Venus-Mercury 1973 link parameters from DSS 14

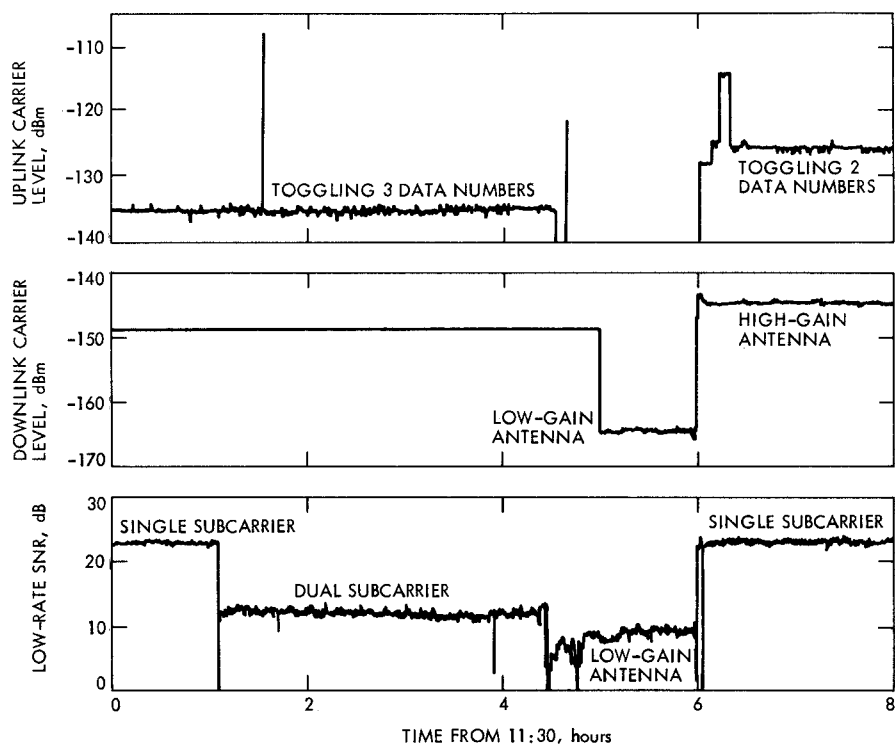


Fig. 5. Digital television hardcopy for typical link conditions without solar effects on communications on September 24, 1976

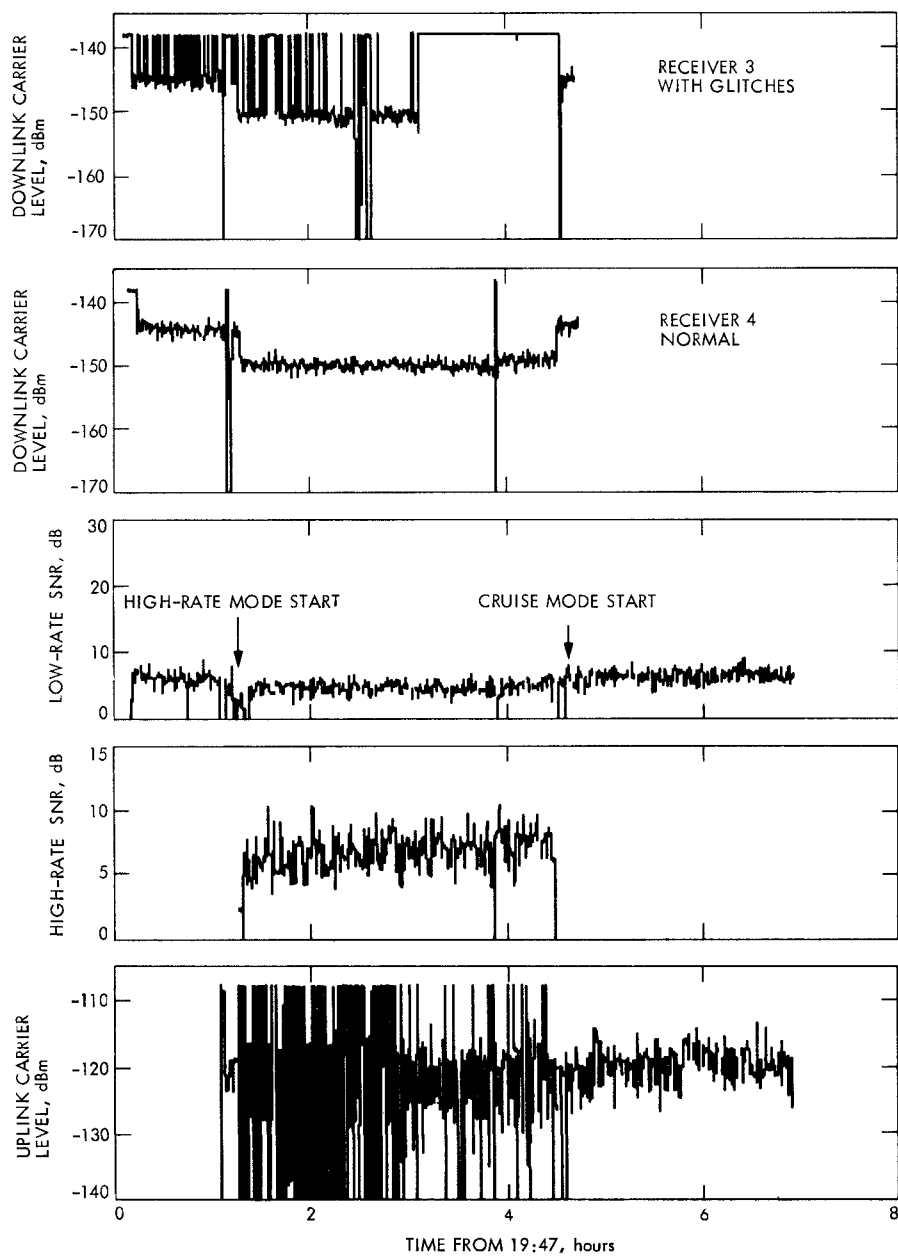


Fig. 6. VO-1 link quantities on November 10, 1976

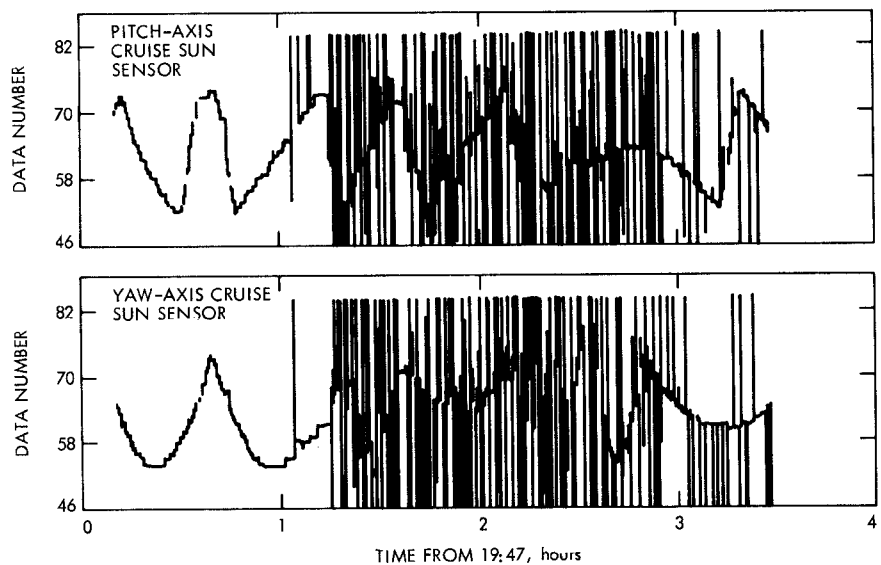


Fig. 7. Attitude control limit cycle telemetry data on November 10, 1976

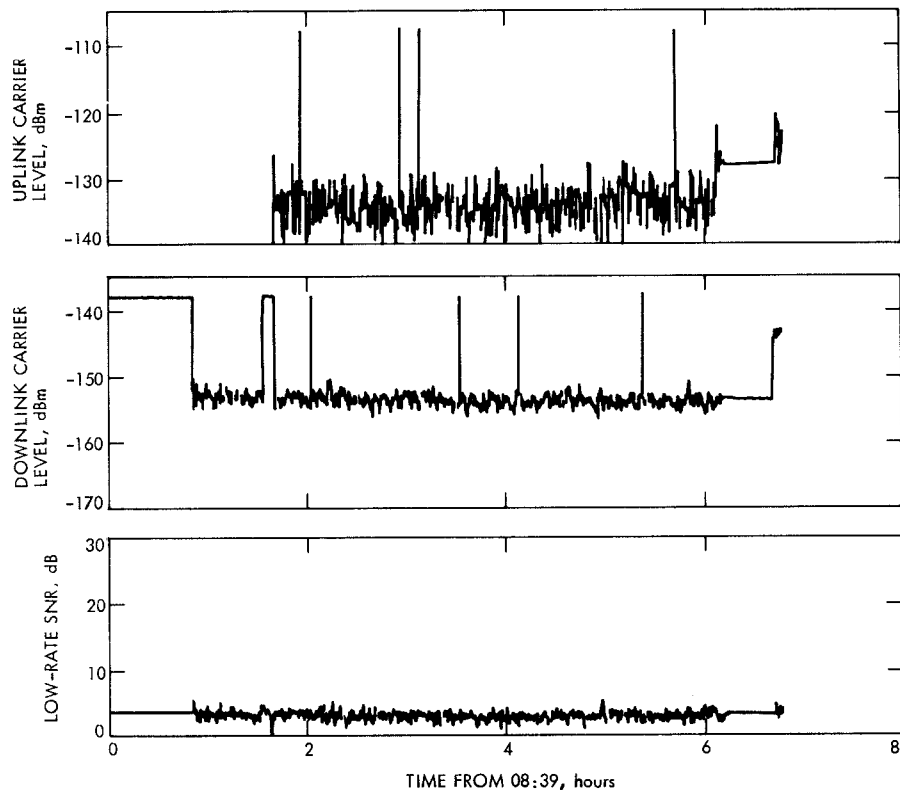


Fig. 8. VO-2 link quantities on November 15, 1976

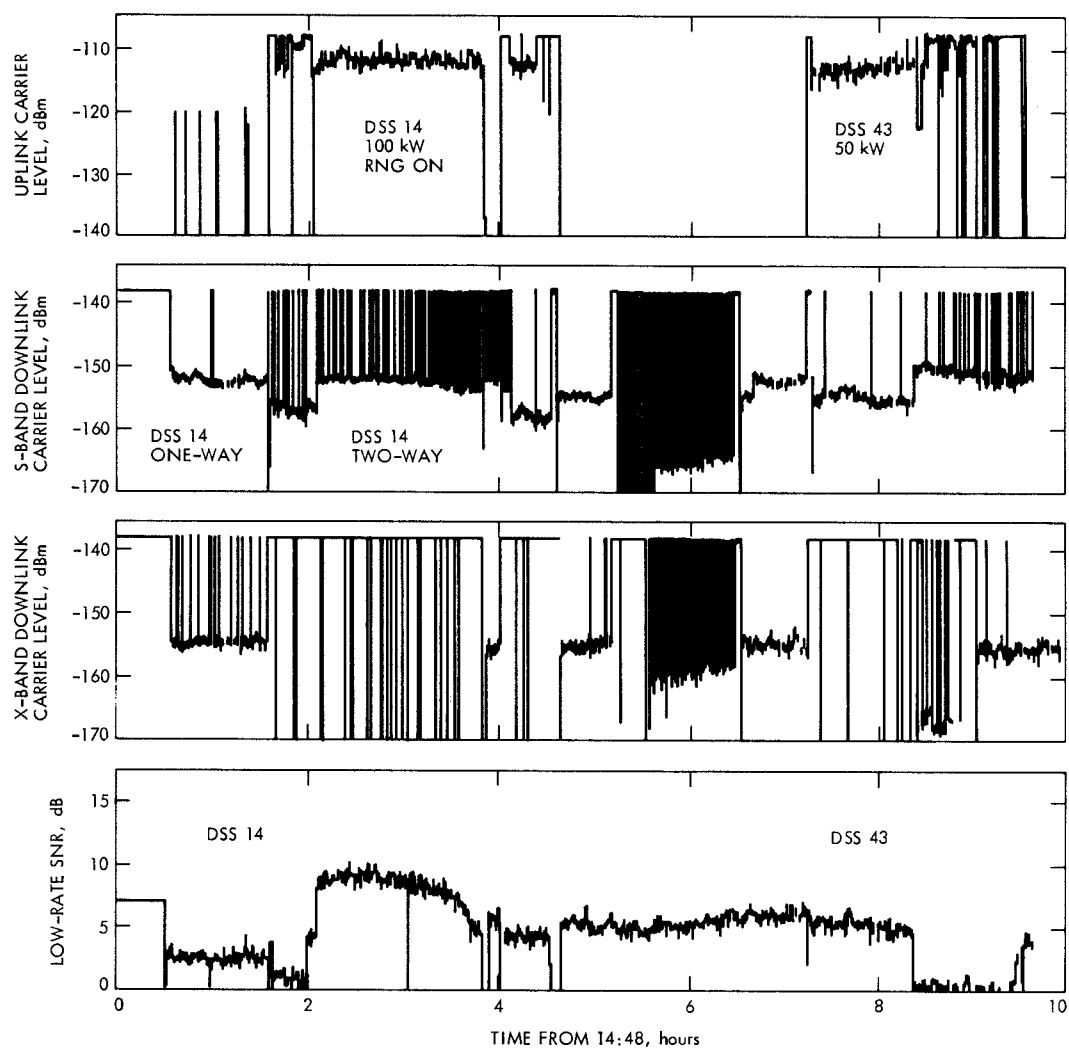


Fig. 9. VO-2 link quantities on November 22, 1976

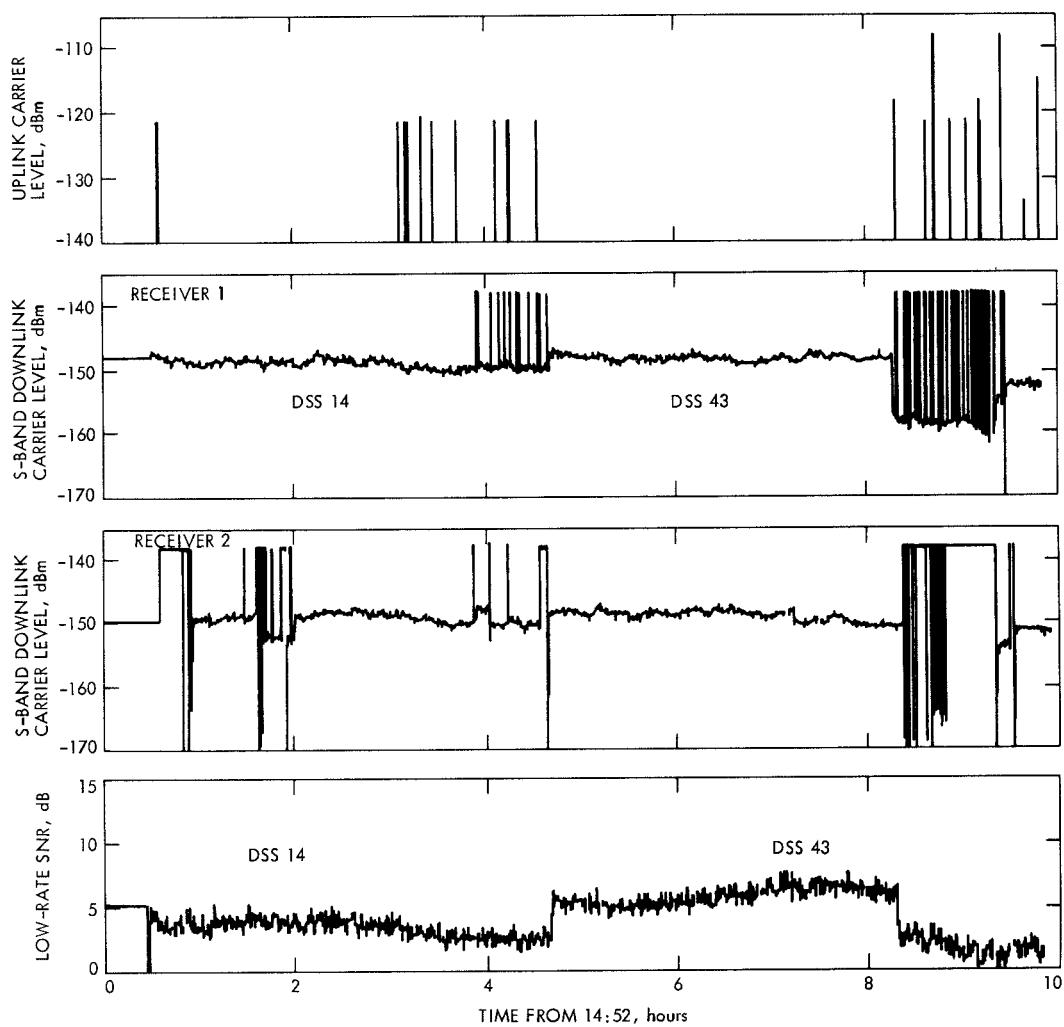


Fig. 10. VO-1 link quantities on November 22, 1976

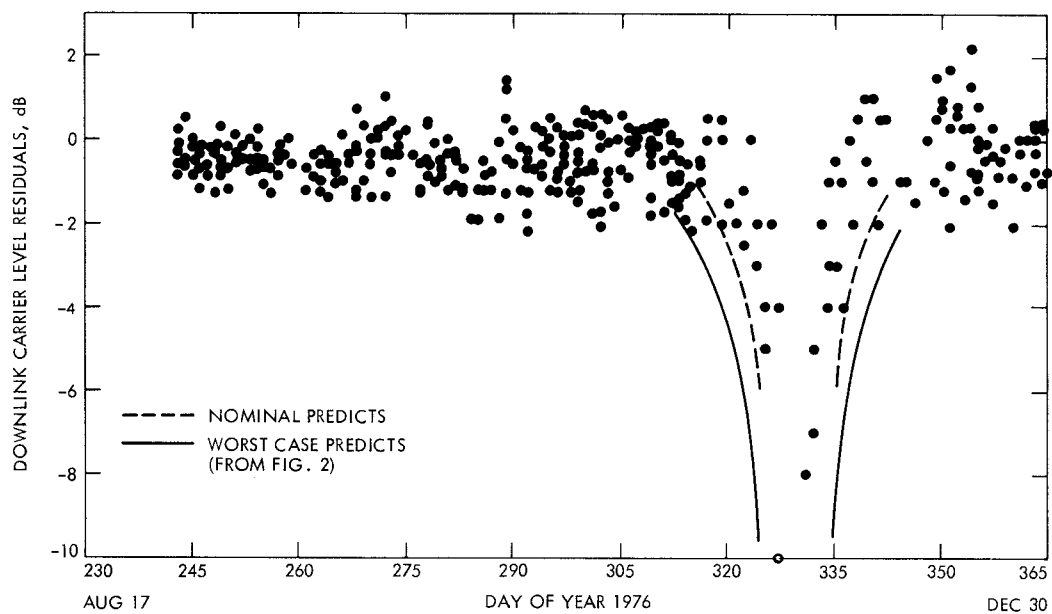


Fig. 11. VO-2 S-band downlink signal level residuals (64-m net)

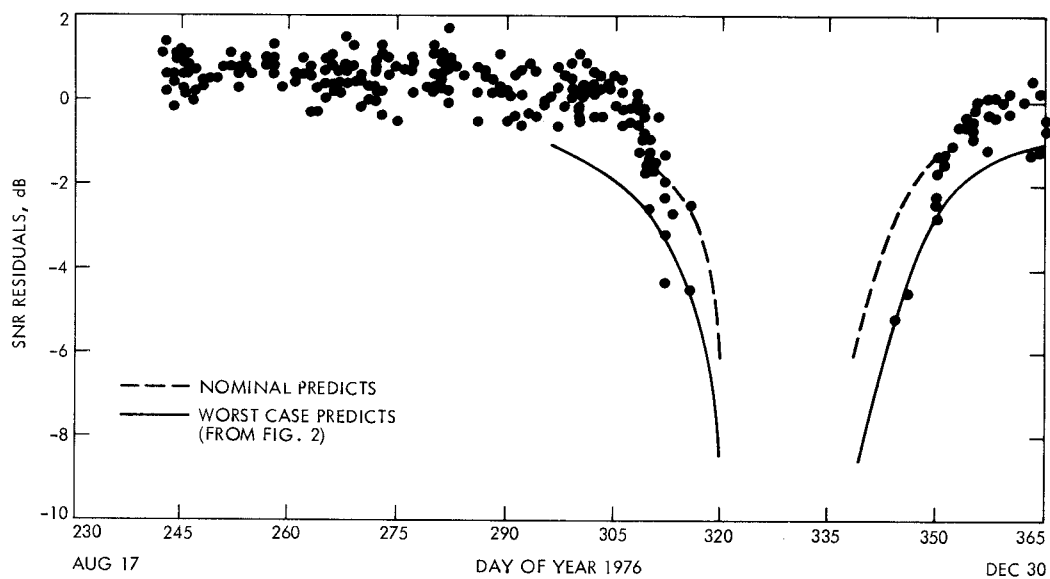


Fig. 12. VO-2 low-rate ($33\frac{1}{3}$ bps) SNR residuals